# IceBridge Ku-Band Radar L1B Geolocated Radar Echo Strength Profiles, Version 1

## USER GUIDE

**How to Cite These Data**

As a condition of using these data, you must include a citation:

Paden, J., J. Li, C. Leuschen, F. Rodriguez-Morales, and R. Hale. 2010, updated 2013. *IceBridge Ku-Band Radar L1B Geolocated Radar Echo Strength Profiles, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/LEZJKNLCJZOW. [Date Accessed].

FOR QUESTIONS ABOUT THESE DATA, CONTACT NSIDC@NSIDC.ORG

FOR CURRENT INFORMATION, VISIT http://nsidc.org/data/IRKUB1B

National Snow and Ice Data Center

# TABLE OF CONTENTS

# 1   DETAILED DATA DESCRIPTION

Operation IceBridge products may include test flight data that are not useful for research and scientific analysis. Test flights usually occur at the beginning of campaigns. Users should read flight reports for the flights that collected any of the data they intend to use. Check IceBridge campaign Flight Reports for dates and information about test flights.

## 1.1 Format

The data set contains binary, MATLAB, JPEG, and KML files.

## 1.2 File and Directory Structure

The files are organized on the following HTTPS site:

`https://daacdata.apps.nsidc.org/pub/DATASETS/ICEBRIDGE/IRKUB1B_KuBandXyEcho_v01/`

The data are divided into segments. A segment is a contiguous data set where the radar settings do not change. A day is divided into segments if the radar settings were changed, hard drives were switched, or other operational constraints required that the radar recording be turned off and on. All data from a particular segment are stored in a directory with the following nomenclature YYYYMMDD_SS where YYYY is the year, MM is the month, DD is the day, and SS is the segment. Segments are always sorted in the order in which the data was collected. Currently at NSIDC, the data directories for 2011 Greenland are named according to this convention, but the 2010 Greenland and 2010 Antarctica directories are not.

Each segment is broken into frames to make analyzing the data easier. Currently frame boundaries align with raw data files. This will not always be the case, but typically a frame represents a few kilometers of data. The frame ID uses the following format YYYYMMDD_SS_FFF.mat where FFF is the frame number.

### 1.2.1   Sub-Directory Folders

The most convenient way to browse the imagery quickly is through the JPEG files. The quickest way to plot the data set is to look at the KML browse files for the entire season.

/CSARP_standard/
Standard Synthetic Aperture Radar (SAR) processed output.

/images/

All of the JPEG files are in this directory. This includes a flight path file and an echogram file. The background images are Landsat-7 natural color imagery in polar stereographic format. Center for Greenland/Canada is 70 degrees true scale latitude, -45 degrees longitude. Center for Antarctica is -71 degrees true scale latitude, 0 degrees longitude.

/kml/

Flight lines for each segment

## 1.3 File Naming Convention

### 1.3.1  Binary Files

The binary files are named according to the following convention and as described in Table 1.

Example: `data00.0180.bin`

`dataNN.XXXX.bin`

Where:

Table 1. Binary File Naming Convention

| Variable | Description |
|---|---|
| data | Indicates data file |
| NN | Day segment |
| XXXX | Flight ID number |
| .bin | Indicates a binary file |

### 1.3.2  MATLAB Files

The MATLAB files are named according to the following convention and as described in Table 2.

Example: `Data_20110316_01_011.mat`

`Data_YYYYMMDD_SS_FFF.mat`

Where:

Table 2. MATLAB File Naming Convention

| Variable | Description |
|----------|-------------|
| Data | Indicates data file |
| YYYY | Four-digit year |
| MM | Two-digit month |
| DD | Two-digit day |
| SS | Day segment |
| FFF | Frame number |
| .mat | Indicates a MATLAB file |

## 1.3.3   GPS MATLAB Files

The GPS MATLAB files are named according to the following convention and described in Table 3.

gps.mat

Where:

Table 3. GPS MATLAB File Naming Convention

| Variable | Description |
|----------|-------------|
| gps | Indicates Global Positioning System file |
| .mat | Indicates MATLAB file |

## 1.3.4   FFT Image JPEG Files

The FFT image JPEG files are named according to the following convention and as described in Table 4.

Example: FFT_image.00.0001.jpg

FFT_image.nn.xxxx.jpg

Where:

Table 4. FFT Image JPEG File Naming Convention

| Variable | Description |
|----------|-------------|
| FFT_image | Echogram browse image |
| nn | Day segment |
| xxxx | Flight ID number |
| .jpg | Indicates a JPEG image file |

## 1.3.5   Flight Path Image JPEG Files

The flight path image JPEG files are named according to the following convention and as described in Table 5.

Example: `Flight_Path.00.0001.jpg`

`Flight_Path.nn.xxxx.jpg`

Where:

Table 5. Flight Path Image JPEG File Naming Convention

| Variable | Description |
|---|---|
| Flight_Path | Flight path location plot |
| nn | Day segment |
| xxxx | Flight ID number |
| .jpg | Indicates a JPEG image file |

## 1.3.6   JPEG Image Files

The JPEG image files have the naming conventions shown below and as described in Table 6.

Examples:
`20110317_02_000_131005_0maps.jpg`
`20110317_02_000_131005_1echo.jpg`

`YYYYMMDD_SS_FFF_HHmmss_0maps.jpg`
`YYYYMMDD_SS_FFF_HHmmss_1echo.jpg`

Where:

Table 6. JPEG Image File Naming Variables

| Variable | Description |
|---|---|
| YYYY | Four-digit year |
| MM | Two-digit month |
| DD | Two-digit day |
| SS | Segment number |
| FFF | Frame number |
| HH | Hour, 00-23 |
| mm | Minute, 00-59 |
| ss | Second, 00-59 |

| Variable | Description |
|----------|-------------|
| 0maps | Flight path file |
| 1echo | Echogram file |
| .jpg | Indicates JPEG image file |

### 1.3.7   KML Files

The KML files have the naming conventions shown below and as described in Table 7.

Example: `Browse_Data_20110316_01.kml`

`Browse_Data_YYYYMMDD_SS.kml`

Where:

Table 7. KML File Naming Variables

| Variable | Description |
|----------|-------------|
| Browse_Data | Browse file |
| YYYY | Four-digit year |
| MM | Two-digit month |
| DD | Two-digit day |
| SS | Segment number |
| .kml | Indicates KML file |

## 1.4 File Size

Binary files range from approximately 12 MB to 24 MB.

MATLAB files are approximately 1 MB each.

JPEG files are approximately 272 KB to 16 MB.

KML files range from approximately 1 KB to 320 KB.

## 1.5 Volume

The entire data set is approximately 4.2 TB.

## 1.6 Spatial Coverage

Spatial coverage for this data set includes the Arctic, Greenland, Antarctica, and surrounding ocean areas. In effect, this represents the two coverages noted below.

Arctic / Greenland:

Southernmost Latitude: 60° N

Northernmost Latitude: 90° N

Westernmost Longitude: 180° W

Easternmost Longitude: 180° E

Antarctic:

Southernmost Latitude: 90° S

Northernmost Latitude: 53° S

Westernmost Longitude: 180° W

Easternmost Longitude: 180° E

### 1.6.1   Spatial Resolution

Spatial Resolution varies dependent on along-track, cross-track, and aircraft height characteristics. See the Derivation Techniques and Algorithms section for further detail on resolution and bandwidth.

### 1.6.2   Projection and Grid Description

Referenced to WGS-84 Ellipsoid.

## 1.7 Temporal Information

26 March 2010 to 17 May 2012

### 1.7.1   Temporal Resolution

IceBridge campaigns are conducted on an annual repeating basis. Arctic and Greenland campaigns are conducted during March, April, and May; Antarctic campaigns are conducted during October and November.

## 1.8 Parameter or Variable

This data set contains elevation and surface measurements.

### 1.8.1   Parameter Description

The Ku-band Radar MATLAB files contain fields as described in Table 8.

Table 8. MATLAB File Parameter Description

| Parameter | Description | Units |
| --- | --- | --- |
| Data | Radar echogram data. The data may be truncated. Presence of the Truncate_Bins variable indicates Data has been truncated. Lack of the Truncate_Bins variable indicates Data has not been truncated. | Represents relative received power (Watts) |
| Time | Fast time. Zero time is approximately the beginning of the transmit event. | Seconds |
| Depth | Range axis with the origin at the median of the Surface values in this frame and assuming a dielectric of 1.53 (Depth = (Time - median(Surface)) * c/2/sqrt(1.53)) | Meters |
| Truncate_Bins | These are the indices into the Time and Depth vectors. Only available when Data is truncated. | n/a |
| Truncate_Mean | Represents a mean of the noise power for the truncated range bins before the surface return. When no range bins were truncated before the surface return, the value is NaN. Only available when Data is truncated. | n/a |
| Truncate_Median | Represents a median of the noise power for the truncated range bins before the surface return. When no range bins were truncated before the surface return, the value is NaN. Only available when Data is truncated. | n/a |
| Truncate_Std_Dev | Represents a standard deviation of the noise power for the truncated range bins before the surface return. When no range bins were truncated before the surface return, the value is NaN. Only available when Data is truncated. | n/a |
| GPS_Time | GPS time when data were collected, seconds since January 1, 1970 00:00:00. This is the ANSI C standard. | Seconds |
| Latitude | WGS-84 geodetic latitude coordinate. Always referenced to North. Represents the location of the origin of the trajectory data which is generally not the radar's phase center, but some other point on the aircraft, for example the GPS antenna or the INS. | Degrees |
| Longitude | WGS-84 geodetic longitude coordinate. Always referenced to East. Represents the location of the origin of the trajectory data which is generally not the radar's phase center, but some other point on the aircraft, for example the GPS antenna or the INS. | Degrees |

| Parameter | Description | Units |
|---|---|---|
| Elevation | Referenced to WGS-84 ellipsoid. Positive is outward from the center of the Earth. Represents the location of the origin of the trajectory data which is generally not the radar's phase center, but some other point on the aircraft, for example the GPS antenna or the INS. | Meters |
| Elevation_Correction | Represents the number of zeros that were inserted during elevation compensation for each range line to simulate near-level flight. These zeros are not included in the truncation noise statistics. Only available when data are elevation compensated. | Range bins |
| Surface | Estimated two way propagation time to the surface from the collection platform. This uses the same frame of reference as the Time variable. This information is sometimes used during compression to determine the range bins that can be truncated. | Seconds |
| *param* | Multiple variables with a name containing the string "param." Contains radar and processing settings, and processing software version and time stamp information. Fields of structures are not static and may change from one version to the next. | n/a |

# 2   SOFTWARE AND TOOLS

Binary files may be opened using ENVI and other similar software.

MATLAB files may be opened using MATLAB or Octave.

A MATLAB image browser is available from CReSIS.

JPEG files may be opened using any image viewing software capable of reading JPEG files.

KML files are used by GIS software and earth browsers such as Google Earth, Google Maps.

# 3   DATA ACQUISITION AND PROCESSING

## 3.1 Data Acquisition Methods

The Ku-band radar uses a Frequency Modulated Continuous Wave (FMCW) architecture (Carrara, 1995). This is done to reduce the required sampling frequency of the Analog to Digital Converter (ADC) and is possible when the range gate is limited. Currently, the range gate is limited to low altitude flights to achieve the full bandwidth. In the FMCW radars, a long chirp signal of approximately 250 µs is generated which sweeps linearly in frequency from the start frequency to the stop frequency. This signal is transmitted and also fed to a mixer in the receiver to be used to demodulate the received signal. Signals outside the range gate are suppressed by the Intermediate Frequency (IF) filter and aliased by the system.

The dominant scattered signal is the specular or coherent reflection from the air-snow surface and shallow layers beneath this surface. A bistatic antenna configuration is used to provide isolation between the transmit and receive paths which is important because the FMCW system receives while transmitting and too little isolation means that the direct path from the transmitter to the receiver will be too strong and saturate the receiver. The antennas are mounted so that the main beam is pointed in the nadir direction to capture the specular surface and layer reflections.

The Pulse Repetition Frequency (PRF), or along-track sampling rate, does not necessarily capture the full Doppler bandwidth for point scatterers without aliasing. However, as the target energy is mostly coherent, it occupies only a small portion of the Doppler spectrum so the undersampling in along-track is not generally a problem. Since the coherent portion of the surface and layer scattering is the primary signal of interest, presuming is used to lower the data rate, which effectively low-pass-filters and decimates the Doppler spectrum.

The narrow beam width of the antennas have a fixed pointing direction, which means that when the aircraft rolls beyond approximately 10 degrees, the specular reflection falls outside the main lobe of the antennas and therefore the signal strength is reduced.

## 3.2 Derivation Techniques and Algorithms

Echograms posted include altitude correction, but the binary files do not. Correction can be applied by shifting a record from bottom to top by the altitude correction value. Altitude variations within a data file are removed by subtracting the minimum altitude from all values. The result is variation in meters from the minimum. These values are then converted to whole pixel values given the radar parameters: sampling frequency = 58.32 MHz, pulse length, FFT length, and bandwidth. Note: sampling frequency after the 2009 Greenland campaign is 62.5 MHz.

The MATLAB plotting code below shows how to compensate for elevation so that the echogram data mimics constant elevation flight at the maximum elevation in each data frame.

```matlab
% Example shows snow radar data
load Data_20110323_03_028.mat

% Plot Data without elevation compensation
figure(1); clf;
imagesc(lp(Data)); colormap(1-gray(256)); ylim([5750 6000]);
xlabel('Range line');
ylabel('Range bin');

% Plot Elevation without elevation compensation
figure(2); clf;
plot(Elevation);
xlabel('Range line');
ylabel('Elevation (m)');

% Elevation compensate data
c = 2.997924580003452e+08;
dt = Time(2)-Time(1);
dr = dt*c/2;
max_elev = max(Elevation);
% This routine only compensates with range bin resolution accuracy
for rline = 1:size(Data,2)
  Data(:,rline) = circshift(Data(:,rline),round((max_elev-
Elevation(rline))/dr));
end
Elevation(:) = max_elev;

% Plot Data with elevation compensation
figure(3); clf;
imagesc(lp(Data)); colormap(1-gray(256)); ylim([5750 6000]);
xlabel('Range line');
ylabel('Range bin');

% Plot Elevation after elevation compensation
figure(4); clf;
plot(Elevation);
xlabel('Range line');
ylabel('Elevation (m)');

return;
```

Figure 1. MATLAB Plotting Code

Figure 2 illustrates an echogram with and without elevation compensation.
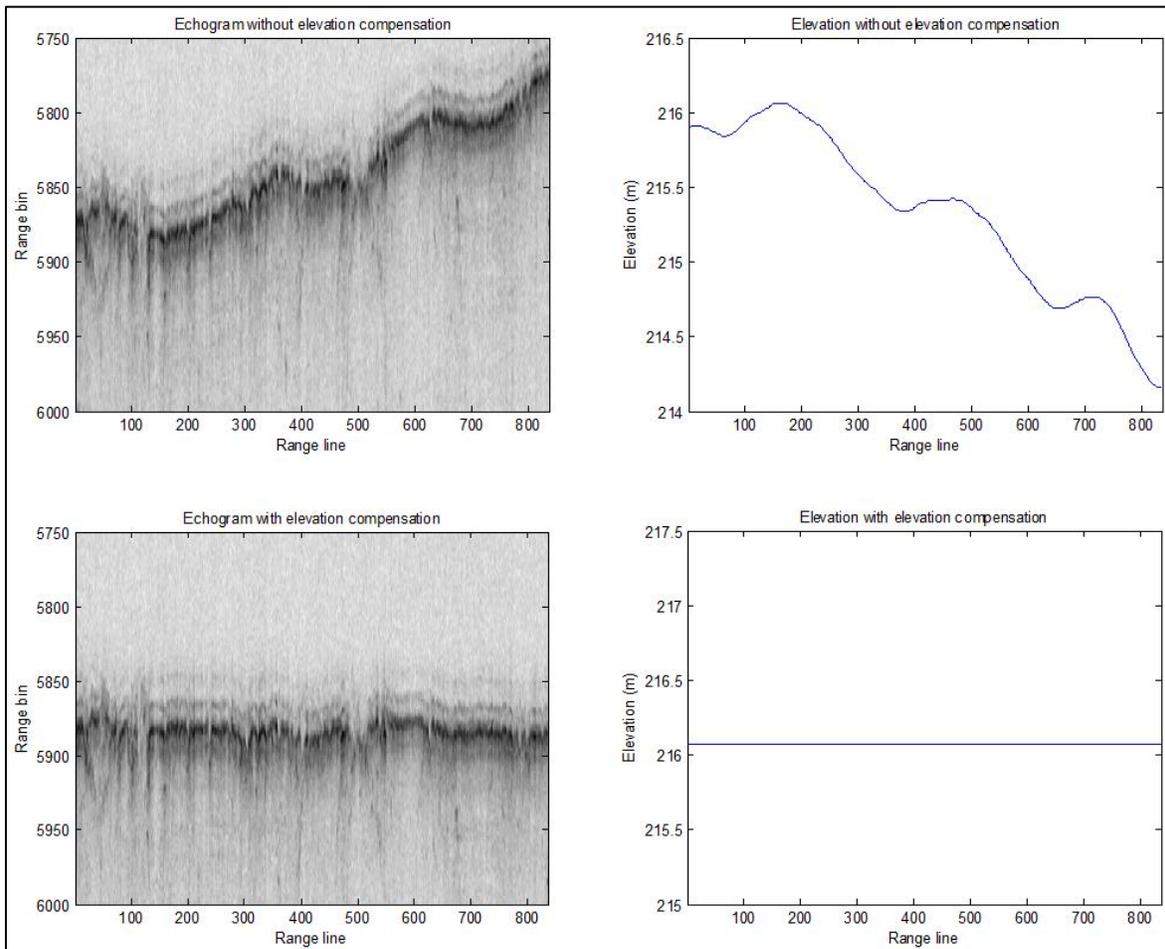
Figure 2. Elevation Compensation Echogram

## 3.2.1   Flat Surface Range Resolution

For a flat surface the range resolution is expressed by Equation 1:

$$r = \frac{k_t \cdot c}{2 \cdot B \cdot n}$$ **(Equation 1)**

Where:

Table 9. Flat Surface Range Resolution

| Variable | Description |
|---|---|
| $k_t$ | $k_t$ = 1.5 due to the application of a Hanning time-domain window to reduce the range sidelobes of the chirped transmit waveform. |
| $c$ | Speed of light in a vacuum |
| B | Bandwidth, nominally 3500 MHz (13 to 16.5 GHz range) |
| n | Index of refraction for the medium |

## 3.2.2   Bandwidth

The bandwidth for a particular segment can be determined by reading the param_radar structure in the echogram data file or by looking at the parameter values f0, f1, and fmult and doing the calculation in Equation 2:

$$B = (param\_radar.f1 - param\_radar.f0) * param\_radar.fmult \quad \text{(Equation 2)}$$

Where:

Table 10. Bandwidth

| Variable | Description |
|----------|-------------|
| B | Bandwidth |
| param_radar.f1 | Stop frequency of chirp out of Direct Digital Synthesis (DDS) and into Phase-Locked Loop (PLL) |
| param_radar.f0 | Start frequency of chirp out of DDS and into PLL |
| param_radar.fmult | PLL frequency multiplication factor |

The range resolutions for several indices of refraction are shown in Table 11.

Table 11. Range Resolutions

| Index of Refraction | Range Resolution (cm) | Medium |
|---------------------|-----------------------|--------|
| 1 | 6.4 | Air |
| sqrt(1.53) | 5.2 | Snow |
| sqrt(3.15) | 3.6 | Solid Ice |

## 3.2.3   Index of Refraction

The index of refraction can be approximated by the calculation in Equation 3:

$$n = \left(1 + 0.51\rho_{snow}\right)^3 \quad \text{(Equation 3)}$$

Where:

Table 12. Index of Refraction

| Variable | Description |
|----------|-------------|
| $\rho_{snow}$ | Density of the snow in grams per cm3 |

A dielectric of 1.53 is used which corresponds to a snow density of 0.3 g per cm$^3$ (Warren, 1999).

## 3.2.4 Along Track Resolution

In the along-track dimension, the raw data, before any hardware or software coherent averages, have a resolution derived in the same manner as the cross-track resolution. However, a basic form of focusing is applied called unfocussed SAR processing, also known as stacking or coherent averaging. If all effects are accounted for, the data may be coherently averaged to a SAR aperture length using Equation 4.

$$L = \sqrt{\frac{H\lambda_c}{2}}$$  **(Equation 4)**

Where:

Table 13. SAR Aperture Length

| Variable | Description |
|---|---|
| $H$ | Height above ground |
| $\lambda_c$ | Wavelength |

For H = 500 m and a center frequency of 14.75 GHz, the data may be averaged to a length of 2.25 m. The resolution turns out to be approximately equal to this with the exact definition given below. However, these data are only coherently averaged 16 times which includes both hardware and software averaging, and decimated by this same amount. At a platform speed of 140 m/s this is an aperture length, L, of 1.12 m. The sample spacing is likewise 1.12 m. Therefore, the actual resolution is less fine, given by Equation 5.

$$\sigma_{x,SAR-qlook} = H \tan\left(\sin^{-1}\left(\frac{\lambda_c}{2L}\right)\right)$$  **(Equation 5)**

Where:

Table 14. Along Track Resolution

| Variable | Description |
|---|---|
| $H$ | Height above ground |
| $\lambda_c$ | Wavelength |
| $L$ | SAR aperture length |

For $H$ = 500 m, the along-track resolution is 4.54 m.

A 1 range-bin by 5 along-track-range-line boxcar filter is applied to the power detected data and then decimated in the along-track by 5 so the data product has an along-track sample spacing of 5.6 m.

## 3.2.5   Fresnel Zone and Cross Track Resolution

For a smooth or quasi-specular target, for example internal layers, the primary response is from the first Fresnel zone. Therefore, the directivity of specular targets effectively creates the appearance of a cross-track resolution equal to this first Fresnel zone. The first Fresnel zone is a circle with diameter given by Equation 6.

$$\sigma_{y,\text{Fresnel-limited}} = \sqrt{2\left(H + T/\sqrt{3.15}\right)\lambda_c} \quad \textbf{(Equation 6)}$$

Where:

Table 15. First Fresnel Zone Diameter

| Variable | Description |
|----------|-------------|
| $H$ | Height above the air/ice interface |
| $T$ | Depth in ice of the target |
| $\lambda_c$ | Wavelength at the center frequency |

Table 16 gives the cross-track resolution for this case.

Table 16. Cross-track Resolution Case

| Center Frequency (MHz) | Cross-track Resolution<br>H = 500 m<br>T = 0 m |
|------------------------|------------------------------------------------|
| 14750 | 4.5 |

For a rough surface with no appreciable layover, the cross-track resolution will be constrained by the pulse-limited footprint, approximated in Equation 7.

$$\sigma_{y,\text{pulse-limited}} = 2\sqrt{\frac{\left(H + T/\sqrt{3.15}\right)ck_t}{B}} \quad \textbf{(Equation 7)}$$

Where:

Table 17. Pulse-Limited Footprint

| Variable | Description |
|----------|-------------|
| $H$ | Height above the air/ice interface |
| $T$ | Depth in ice of the target |
| c | Speed of light in a vacuum |
| $k_t$ | $k_t = 1.5$ due to the application of a hanning time-domain window to reduce the range sidelobes of the chirped transmit waveform |
| $B$ | Bandwidth in radians |

Table 18 gives the cross-track resolution with windowing.

Table 18. Cross-track Resolution with Windowing

| Bandwidth (MHz) | Cross-track Resolution H = 500 m T = 0 m |
|-----------------|-------------------------------------------|
| 3500 | 16.0 |

For a rough surface where layover occurs, the cross-track resolution is set by the beamwidth, β, of the antenna array. The antenna beamwidth-limited resolution is expressed by Equation 8:

$$\sigma_{y,\text{beamwidth-limited}} = 2\left(H + \frac{T}{\sqrt{3.15}}\right)\tan\left(\frac{\beta_y}{2}\right)$$

(Equation 8)

Where:

Table 19. Antenna Beamwidth-limited Resolution

| Variable | Description |
|----------|-------------|
| $H$ | Height above ground level |
| $T$ | Depth in ice of the target |
| $\beta_y$ | Beamwidth in radians |

## 3.2.6 Footprint

The antenna installed in the bomb bay of the NASA P-3 aircraft, the wing roots of the DC-8, and the nadir port of the Twin Otter is a Pasternack Enterprises 9854-20 standard gain horn antenna. The E-plane of the antenna is aligned in the along-track. The approximate beamwidths are 19 degrees in along-track and 19 degrees in cross-track. The footprint is a function of range as shown in Equation 9.

$$\sigma = 2H \tan\left(\frac{\beta}{2}\right)$$ **(Equation 9)**

Where:

Table 20. Footprint

| Variable | Description |
|----------|-------------|
| β | Beamwidth in radians |
| $H$ | Height above ground level |

For $H$ = 500 m, the footprint is 167 m in along-track and 167 m in cross-track.

### 3.2.7   Trajectory and Attitude Data

The trajectory data used for this data release was from a basic GPS receiver. Lever arm and attitude compensation has not been applied to the data.

### 3.2.8   Processing Steps

The following processing steps are performed by the data provider.

1.  Set digital errors to zero. Error sequences are four samples in length and occur once every few thousand range lines.
2.  Synchronization of GPS data with the radar data using the UTC time stored in the radar data files.
3.  Conversion from quantization to voltage at the ADC input.
4.  Removal of DC-bias by subtracting the mean.
5.  The quick look output is generated using presuming or unfocused SAR processing for a total of 16 coherent averages which includes hardware and software averages. If the PRF is 2000 Hz, the new effective PRF is 125 Hz.
6.  A fast-time FFT is applied with a Hanning window to convert the raw data into the range domain, analogous to pulse compression. The data are flipped around based on the Nyquist zone.
7.  A high pass filter is applied in the along-track to remove coherent noise.
8.  A 1 range-bin by 5 along-track-range-line boxcar filter is applied to the power detected data and then decimated by 5 in along-track.
9.  The quick-look output is used to find the ice surface location, fully automated.
10. The output is then elevation compensated with radar range bin accuracy, and then truncated in fast time.

The purpose of the elevation compensation, when applied, is to remove the large platform elevation changes to make truncation more effective. The process is not designed to perform

precision elevation compensation and is probably not sufficient for scientific analysis. The following steps are performed:

1. Let:
   a. Elevation_Orig be the 1 by N elevation vector before elevation compensation
   b. Data_Orig be the M_orig by N data matrix before elevation compensation
   c. Time_Orig be the M_orig by 1 fast-time time axis before elevation compensation
   d. Elevation be the 1 by N vector from the data product file
   e. Dat be the matrix from the data product file
   f. Time be the M by 1 fast-time time axis from the data product file
   g. maxElev = max(Elevation_Original)
2. dRange = maxElev - Elevation_Original
3. dt = Time_Orig(2) - Time_Orig (1)
   a. Sample spacing in fast-time (i.e. one range bin)
4. dBins = round(dRange / (c/2) / dt)
   a. This is a 1 by N vector of the number of range bins for each range line used to shift "Data_Orig". In other words, this is the elevation compensation for each range line written in terms of range bins.
5. M = M_orig + max(dBins)
6. The original data matrix is zero padded to M and then each range line is shifted by the corresponding entry in dBins.
   a. Because of the round function for creating dBins, the elevation compensation is only done with range bin accuracy.
   b. The new Data matrix is similar to what would have been collected if the aircraft had flown at a constant elevation of maxElev.
7. The elevation matrix is modified according to the elevation compensation so that: Elevation_Orig = Elevation - dBins*dt*c/2. Once again, because of the round function, the Elevation vector will be nearly constant, but not quite: the quantization noise caused by the round function remains.
8. The Time_Orig vector is extended in length by the maximum bin shift to create the new Time vector.

## 3.2.9   Version History

On August 19, 2011, the 2010 Ku-Band Level-1B Greenland data were replaced by V1.1. For some days the variable record length in the header was more than one 32 bit integer when it should be one 32 bit integer. This offset the records. This is corrected in the August 19, 2011 replacement data.

Version 2 IRKUB1B data: beginning with the 2012 Antarctica campaign, all data are provided in netCDF format. In the near future, all Version 1 data will be replaced with netCDF data. For more on Version 2 IRKUB1B data see the Version 2 documentation.

## 3.2.10 Error Sources

The CReSIS ku-band, accumulation, and snow data acquisition systems have a known issue with radar data synchronization with GPS time. When the radar system is initially turned on, the radar system acquires Universal Time Coordinated (UTC) time from the GPS National Marine Electronics Association (NMEA) string. If this is done too soon after the GPS receiver has been turned on, the NMEA string sometimes returns GPS time rather than UTC time. GPS time is 15 seconds ahead of UTC time during this field season. The corrections for the whole day must include the offset -15 second correction. GPS corrections have been applied to all of the data using a comparison between the accumulation, snow, and kuband radars which have independent GPS receivers. A comparison to geographic features and between ocean surface radar return and GPS elevation is also made to ensure GPS synchronization. GPS time corrections are given in the vector worksheet of the parameter spreadsheet.

## 3.3 Sensor or Instrument Description

As described on the CReSIS Sensors Development Radar website, the ku-band radar operates over the frequency range from 13 to 17 GHz. The primary purpose of this radar is high precision surface elevation measurements over polar ice sheets. The data collected with this radar can be analyzed in conjunction with laser-altimeter data to determine thickness of snow over sea ice. The radar has been flown on the NASA DC-8 and P-3 aircrafts, and the National Science Foundation-provided Twin Otter aircraft.

# 4    REFERENCES AND RELATED PUBLICATIONS

Carrara, W. G., R. S. Goodman, and R. M. Majewski. 1995. *Spotlight Synthetic Aperture Radar: Signal Processing Algorithms*, Artech House, Norwood, MA, pp. 26-31.

Patel, A. E., P. S. Gogineni, C. Leuschen, F. Rodriguez-Morales, and B. Panzer. 2010. An Ultra Wide-band Radar Altimeter for Ice Sheet Surface Elevation and Snow Cover Over Sea Ice Measurement, Abstract C41A-0518 presented at 2010 Fall Meeting, AGU, San Francisco, California, 13-17 December, 2010.

Rodriguez-Morales, F., P. Gogineni, C. Leuschen, C. T. Allen, C. Lewis, A. Patel, L. Shi, W. Blake, B. Panzer, K. Byers, R. Crowe, L. Smith, and C. Gifford. 2010. Development of a Multi-Frequency Airborne Radar Instrumentation Package for Ice Sheet Mapping and Imaging, *Proc. 2010 IEEE Int. Microwave Symp.*, Anaheim, CA, May 2010, 157-160.

Warren, S., I. Rigor, and N. Untersteiner. 1999. Snow Depth on Arctic Sea Ice, *Journal of Climate*, 12: 1814-1829.

## 4.1 Related Data Collections

IceBridge Accumulation Radar L1B Geolocated Radar Echo Strength Profiles

IceBridge MCoRDS L1B Geolocated Radar Echo Strength Profiles

IceBridge MCoRDS L2 Ice Thickness

## 4.2 Related Websites

CReSIS Sensors Development Radar website

CReSIS website

IceBridge product website

IceBridge website at NASA

ICESat/GLAS website at NASA Wallops Flight Facility

ICESat/GLAS website at NSIDC

# 5 CONTACTS AND ACKNOWLEDGEMENTS

**Center for Remote Sensing of Ice Sheets (CReSIS)**

Nichols Hall, The University of Kansas

2335 Irving Hill Road

Lawrence, Kansas 66045

data@cresis.ku.edu

Acknowledgments:

The radar systems and software were developed with funding from a variety of sources including NASA (NNX16AH54G), NSF (ACI-1443054), and the State of Kansas. The Operation IceBridge data were collected as part of the NASA Operation IceBridge project. The processing requires GPS and attitude data that are made available by various groups including the Airborne Topographic Mapper team, the Digital Mapping System team, and the Sanders Geophysics company. We also acknowledge all the personnel involved in supporting the field operations.

# 6 DOCUMENT INFORMATION

## 6.1 Publication Date

July 2012

## 6.2 Date Last Updated

February 2019